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Dynamic characteristics of soil respiration in Yellow River Delta wetlands, China

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ABSTRACT

The stable soil carbon (C) pool in coastal wetlands, referred to as "blue C", which has been extensively damaged by climate change and soil degradation, is of importance to maintain global C cycle. Therefore, to investigate the dynamic characteristics of soil respiration rate and evaluate C budgets in coastal wetlands are urgently. In this study, the diurnal and seasonal variation of soil respiration rate in the reed wetland land (RL) and the bare wetland land (BL) was measured *in situ* with the dynamic gas-infrared CO_2 method in four seasons, and the factors impacted on the dynamic characteristics of soil respiration were investigated. The results showed that the diurnal variation of soil respiration rate consistently presented a "U" curve pattern in April, July, and September, with the maximum values at 12:00 a.m. and the minimum values at 6:00 a.m. In the same season, the diurnal soil respiration rate in RL was significantly greater than those in BL ($P < 0.05$). In April, July, and September, the mean diurnal soil respiration rate was 0.14, 0.42, and 0.39 μmol m^{-2} s^{-1} in RL, 0.05, 0.22, 0.13, and 0.01 μmol m^{-2} s^{-1} in BL, respectively. Soil surface temperature was the primary factor that influenced soil respiration, which was confirmed by the exponential positive correlation between the soil respiration rate and soil surface temperature in BL and RL ($P < 0.05$). In addition, the high salinity of soils suppressed soil respiration, confirming by the significantly negative correlation between soil respiration rate and the content of soluble salt. These results will be useful for understanding the mechanisms underlying soil respiration and elevating C sequestration potential in the coastal wetlands.

1. Introduction

Wetland constitutes approximately 6.4% of the Earth's land, but it can substantially sequester 225 Pg (billion tons) of carbon (C) stocks (IPCC, 2013), accounting for 20–25% of the global soil organic C (SOC) reservoir (Jansson et al., 2010; Yu et al., 2012). Consequently, SOC accumulation and mineralization in the wetlands play crucial roles in global C cycling and climate change (Fennessy, 2014). Coastal wetlands (e.g., mangroves, tidal salt marshes, and seagrasses) could provide numerous benefits for climate adaptation and resilience through water quality regulation, erosion prevention and sediment trapping (Howard et al., 2014). Yet coastal wetlands have experienced dramatic losses and deterioration over the past several decades due to climate change (e.g., greenhouse effect, sea level rise) and anthropogenic disturbances (e.g., reclamation, deforestation, and urbanization) (Mcleod et al., 2011). Approximately one-third of coastal wetlands has disappeared, and thus resulted in 0.15–1.02 Pg of CO_2 emission annually from the C pool of coastal wetlands (Pendleton et al., 2012). This also caused economic damages of $US 6–42 billion annually (Pendleton et al., 2012). In recognition of the severe status, assessing C sequestration abilities of the coastal wetlands with or without remediation, has been attracted more and more attention (Mcleod et al., 2011; Vaidyanathan, 2011). As the natural C reservoirs, wetland soils accumulated over 90% of total wetlands C, and the dynamics of SOC pools in coastal wetlands directly affected the capacity and roles of coastal wetlands in global C cycle (Howard et al., 2014). Therefore, conserving C sequestration abilities of the coastal wetlands has become an urgent task, which needs to investigate the dynamic characteristics of SOC pool (Luo and Xing, 2010; Luo et al., 2016).

Estuary wetland, a special ecosystem with high net primary productivity and C sequestration, located in the crisscross zone

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with severe impact of land-ocean interaction (Chmura et al., 2003; Han et al., 2012; Yu et al., 2012), plays an important role on maintaining regional and global carbon cycle (IPCC, 2013). The Yellow River Delta, the largest newly-developed estuary wetland in China, is one of the most active regions of land-ocean interaction in the world (Kong et al., 2015). Due to the economic development and changing land-use, natural wetlands (e.g., salt marshes) in Yellow River Delta have experienced a dramatic loss and degradation (Han et al., 2012; Zedler and Kercher, 2005). Currently, the coastal wetlands, especially the "C sinks" potential of estuary salt marsh, has become a research hotspot due to global climate change (Couto et al., 2013; Luo and Xing, 2010). Furthermore, accurately assessing the C budget of estuarine wetland and the dynamic changes of C pool in estuarine wetland, would provide significant benefits in recognizing its role in the regional C cycle and scientifically restoring the ecological functions of degraded wetlands.

Soil respiration can release 77.6×10^4 Pg C $year^{-1}$ (IPCC, 2013), accounting for 10% of the atmospheric C content, and equivalent to 10 times of C flux from burning fossil fuel (IPCC, 2013). Soil respiration is the main CO_2 exchange process between soil and atmosphere in global C cycle, thus even a small change in SOC pool could largely contribute to the rise in atmospheric gaseous C (e.g., CO_2), potentially reinforcing the greenhouse-warming effect (Moriyama et al., 2013; Schindlbacher et al., 2012). Several studies have shown that soil temperature and moisture are two key environmental factors responsible for controlling soil respiration (Moyano et al., 2013; Schütt et al., 2014). Seasonal changes of soil temperature and moisture affect soil organic matter (SOM) accumulation and decomposition, thereby driving the temporal variations of soil respiration at different seasons (Han et al., 2012; Luo and Xing, 2010; Zhao et al., 2016). However, Zhang et al. (2016) reported that soil temperature and moisture were not the main factors influencing the diurnal variations of soil respiration in Tianjin estuarine wetland. These inconsistent results could be ascribed to the differences in soil physico-chemical properties (Luo and Xing, 2010; Schütt et al., 2014). Previous studies have documented that the accumulation of salts in soils suppressed cumulative soil respiration through inhibiting SOM accumulation and decomposition (Setia et al., 2011). The coastal soils are stressed by high alkalinity and low productivity primarily due to the seasonal accumulation of salt from sediment deposition and seawater erosion (Luo et al., 2016; Kong et al., 2015; Zhao et al., 2016). In this condition, the effects of environmental factors (e.g., soil temperature, moisture and salinity) on soil respiration could vary with time and space (Han et al., 2012; Luo and Xing, 2010; Zhang et al., 2016). Han et al. (2012) reported that the seasonal variation of soil respiration in the Yellow River Estuary was attributed to the combined effect of soil temperature and soil moisture. Luo and Xing (2010) suggested that soil respiration rate decreased with the rising of soil temperature in Spring, but no significant diurnal variation exhibited in Autumn. Obviously, these findings are not sufficient to accurately evaluate C budgets of the coastal soils in the Yellow River Delta, limiting understanding the roles of coastal soils in global C cycle.

Therefore, the salt-affected estuary wetland in the Yellow River Delta was used as the targeted area, and the diurnal and seasonal variation of soil respiration rate in the reed wetland land (RL) and the bare wetland land (BL) was measured *in situ* with the dynamic gas-infrared CO_2 method. The influencing factors for soil respiration rate were also analyzed to provide theoretical guidance for reducing soil C loss and elevating soil C sequestration capacity, thus to enhance the eco-environment effect and ecological services of the estuarine wetlands. The specific objectives of this study were to (1) investigate the dynamic characteristics of soil respiration in the two different soils with or without vegetation in four seasons and (2) elucidate the mechanisms of environmental factors in affecting soil respiration.

2. Materials and methods

2.1. Study sites

This study was conducted at 13 sampling sites (each 30 × 30 m) distributed randomly in the reed (*Phragmites australis*) land (RL) and bare land (BL), respectively, at the nature reserve in the Yellow River Delta (37° 49′ N, 118° 59′ E). The Yellow River Delta is one of the youngest estuarine wetlands in China (Lu et al., 2016), and its climate is temperate continental monsoon with obvious seasonal changes and includes a rainy summer (Sun et al., 2014). The average annual temperature ranges from 11.5 to 12.4 °C, with the highest monthly temperature of 26.6 °C in July and the lowest of −4.1 °C in January. The Yellow River Delta, located in a semi-arid zone where the annual mean precipitation and evaporation are 600 mm and 1962 mm, respectively. The annual mean air temperature is 11.9 °C, with 196 frostless days (Bai et al., 2015). The monthly maximum precipitation is 227 mm in July and the minimum precipitation is 1.7 mm in January. Approximately 70% of the total annual precipitation occurs in the summer (Kong et al., 2015). The drought index of soil is up to 3.56 (Cui et al., 2009). Most of the low-lying wetland soils are below 10 m in topography, and the hydrologic characteristics of wetland is influenced by the combined effect of fresh water and seawater, surface and underground water. Due to the decreased input of fresh water and seawater intrusion, the wetland soils have been seriously degraded (Spencer et al., 2016; Wang et al., 2016). The salt-affected soil in this region was described as a Fluvisol (FAO, 2000) and developed on mixed loess and alluvium. Natural vegetation in the Yellow River Delta wetlands mainly included reed (*Phragmites australis*), seepweed (*Suaeda heteroptera*), tamarix (*Tamarix chinensis*), (silvergrass) *Triarrhena sacchariflora* and watermifoil (*Myriophyllum spicatum*) (Jiang et al., 2013).

2.2. Soil respiration rate measurements

The soil respiration rate (μmol CO_2 m^{-2} s^{-1}) in the two wetland sites, i.e., RL and BL, were measured with the closed chamber method using the LI-COR 8100 (LI-COR Inc., Lincoln, NE, USA). In each sampling site, three PVC collars (20 cm inside diameter) were inserted into the shallow surface of soils with no living aboveground vegetation. And the stainless-steel fixing hooks (35 cm long and 2.5-mm diameter welding rods) pressed at an approximately 5° angle 30 cm into the soil. The soil temperature and soil moisture at 5 cm depth next to the respirometer in the chamber were recorded simultaneously during CO_2 measurements with a thermal probe (LI-8100-201 Ω, Type E, LI-COR Inc, Lincoln, NE, USA) and a moisture probe (LI-8100-202 EC-5, Decagon Devices, Inc., Pullman, WA, USA) connected to the LI-8100 system (Liu et al., 2016a,b). Any CO_2 diffusion leakage from the surface collars was negligible because that the CO_2 increase inside the chamber was limited by adjusting the chamber closure period. Each observation length was 120 s and the observation interval was 2 s. It took 120 s for the chamber air to return to ambient conditions between the two observations (Han et al., 2012; Luo and Xing, 2010). All measurements were corrected for changes in atmospheric pressure and were calibrated daily a certified standard CO_2 gas. Soil CO_2 efflux rates were calculated using exponential regression model with the LI-8100 file viewer application software (LI-8100/8150 Instruction Manual, LI-COR Inc, Lincoln, NE, USA) (Liu et al., 2016a,b). To minimize measurement errors and avoid equipment damage, all the measurements were made on days without rain or snow. The 24 h continuous soil respiration test was carried out in triplicate in

Spring (April 26–27, 2013), Summer (July 6–7, 2013), Autumn (September 20–21, 2012) and Winter (January 18–19, 2013), respectively.

2.3. Soil sampling and analysis

After the measurement of soil respiration rate in the selected sites, surface soil samples (0–20 cm) were collected. Following removal of visible gravel and roots, the field-moist soil samples were air-dried, then thoroughly mixed and gently passed through a 2-mm sieve. The soil was stored in glass jars at 4 °C for further analysis. The content of total organic carbon (TOC), total inorganic carbon (TIC) and nitrogen (N) were determined using an elemental analyzer (FLASH-2000, Thermo Finnigan, USA). The content of dissolved organic C (DOC) was determined in 0.50 M K_2SO_4 (1:5, w/v) using an organic C (OC) autoanalyzer (TOC-Vario, Elementar, Germany). Total phosphate (TP) content was measured using ICP-MS after microwave digestion (MARS5, CEM, USA) (0.1 g sample + 6 mL concentrated nitric acid). Soil pH was determined in a 1:2.5 (w/v) soil to water slurry using a pH-meter (AB150, Fisher Scientific, USA). The soluble salt (S) content was obtained by a gravimetric method (Luo et al., 2016). Electrical conductivity (EC) was measured in a 1:5 soil to water slurry using a conductivity meter (Cond 3210, WTW, Germany).

2.4. Statistical analysis

The regression analysis between soil respiration rate and soil surface temperature was based on the Van't Hoff model as follows:

$$R = R_{10} \times Q_{10}^{(T-10)/10} \quad (1)$$

where R (umol m^{-2} s^{-1}) is the measured soil respiration rate, T (°C) is the measured soil surface temperature in the field sites, R_{10} (umol m^{-2} s^{-1}) is the basal soil respiration rate at a reference soil temperature of 10 °C, Q_{10} is the temperature sensitivity of R, which represents the proportional change in the rate of soil respiration with a change in soil temperature by 10 °C. R_{10} and Q_{10} were calculated according to the Eq. (1) using the measured values of soil respiration rate and soil temperature (T) separately for each site (Zhou et al., 2013).

The significance of the various parameters was tested by one-way analysis of variance (ANOVA) using Duncan's multiple range test ($P = 0.05$) for the different seasons (i.e., January, April, July, and September), and the least significant difference (LSD) ($P < 0.05$) based on a Student's t-test was used to illustrate the differences between the reed wetland land (RL) and bare wetland land (BL) by means of Statistical Product and Service Solutions Software 20.0 (SPSS 20.0). The correlation was analyzed with the Pearson test (two-tailed) by the means of SPSS 20.0 at $P = 0.05$.

3. Results and discussion

3.1. The physico-chemical properties of the two wetland soils

The mean content of soil TC in RL was 21.5, 19.1, 18.7, and 13.5 g kg^{-1} in January, April, July, and September, respectively (Fig. 1a), and the corresponding TIC was 12.9, 10.6, 14.5, and 11.4 g kg^{-1} (Fig. 1b), accounting for 60.0%, 55.5%, 77.1%, and 84.4% of TC in the soils, respectively. There was no significant difference in the content of TIC among the different seasons ($P > 0.05$). Compared to the RL, the BL had a lower soil TC content, which was 13.7, 17.6, 17.1, and 14.5 g kg^{-1} in January, April, July, and September, respectively (Fig. 1a). The content of TIC in BL was 11.7, 12.2, 15.2, and 13.1 g kg^{-1}, respectively, which accounted for 85.4%, 69.3%, 88.9%, and 90.3% of TC in soils (Fig. 1b). Thus, these results indicated that IC was the major C stocks of soils in these study sites.

The content of SOC, an important index for evaluating soil quality and fertility (Stockmann et al., 2013), not only directly affected the growth and development of vegetation by mediating soil nutrient transformation (Gargouri et al., 2013), but also was an important evaluation indicator of land resources management for sustainable utilization (Sul et al., 2013). The mean content of soil TOC in RL was 8.57, 8.55, and 4.25 g kg^{-1} in January, April, and July, respectively (Fig. 1c). In September, the soil in BL was severely affected by heavy precipitation, the precipitation could stimulate soil respiration in the soil with low water content compared that in the soil with high water content (Liu et al., 2016a,b), which could account for a significant decrease in the soil OC content in BL. In RL grown with reed vegetation, plant biomass could enhance soil C pool (Yan et al., 2011; Zhang et al., 2010). Thus, the content of soil TOC in RL was significantly greater than that in BL ($P < 0.05$) (Fig. 1a and c).

The pH values of soils in BL were 7.78, 7.48, 7.68, and 8.55 in January, April, July, and September, respectively, and the pH values were 7.83, 7.34, 7.89, and 7.78, respectively, for the soils in the RL during the four seasons (Fig. 2a). The results indicated that both two wetland soils were alkaline. In different seasons, the content of soluble salts (S) in RL presented obvious differences, with the values ranged from 16.5 to 25.6 g kg^{-1}, while similar results were not found in the seasonal variation of soluble salts (S) content in RL (Fig. 2b). The results suggested that the soils in BL could be more fragile to be suffered by the seasonal accumulation of salt compared to the RL (Setia et al., 2011; Mavi et al., 2012).

3.2. Diurnal and seasonal variation of soil respiration in different seasons

In winter, the plant activity (e.g., photosynthesis) could be strongly reduced due to low temperature and weak solar light, and soil respiration was not affected by photosynthesis and productivity (Yan et al., 2011; Han et al., 2014). Thereby, the soil respiration rate in the RL grown with vegetation, was not significantly greater than that of BL in January ($P > 0.05$) (Fig. 3a). The diurnal soil respiration rate of RL in January, April, July, and September were significantly greater than those in BL ($P < 0.05$) (Fig. 3b–d) regardless of the seasonal differences. The dynamic variation of diurnal soil respiration rate in both BL and RL consistently presented a “U” curve pattern in April, July, and September (Fig. 1b–d), in which the maximum soil respiration rate was found around at 12: 00 a.m. and the values of soil respiration rate gradually decreased with increasing time, and minimum soil respiration rate appeared around at 6: 00 a.m. Consistently, Liu et al. (2016b) found that soil respiration reached a peak between 13:00 and 15:00 p.m., and the bottom value occurred between 6:00 and 8:00 a.m., coinciding with the highest and the lowest temperature, respectively, suggesting that the low active soil respiration around at 6:00 a.m. was due to the lower soil temperature compared to those of soils at other time. However, there were no apparent differences in the diurnal soil respiration rate at different time in January (Fig. 3a). The diurnal variation of soil respiration rate in the RL was −0.02–0.06, 0.08–0.32, 0.24–0.70, and 0.08–0.85 μmol m^{-2} s^{-1}, with the mean value of 0.02, 0.14, 0.42, and 0.39 μmol m^{-2} s^{-1} in January, April, July, and September, respectively, and significant differences were observed among the four seasons ($P < 0.05$). The mean diurnal soil respiration rate in January was the lowest among those in the four seasons, suggesting that the intensity of soil respiration could be linked with soil temperature (Schütt et al., 2014). Similarly, the BL also had the highest mean diurnal soil respiration rate (i.e., 0.22 μmol m^{-2} s^{-1}) in July, and the lowest

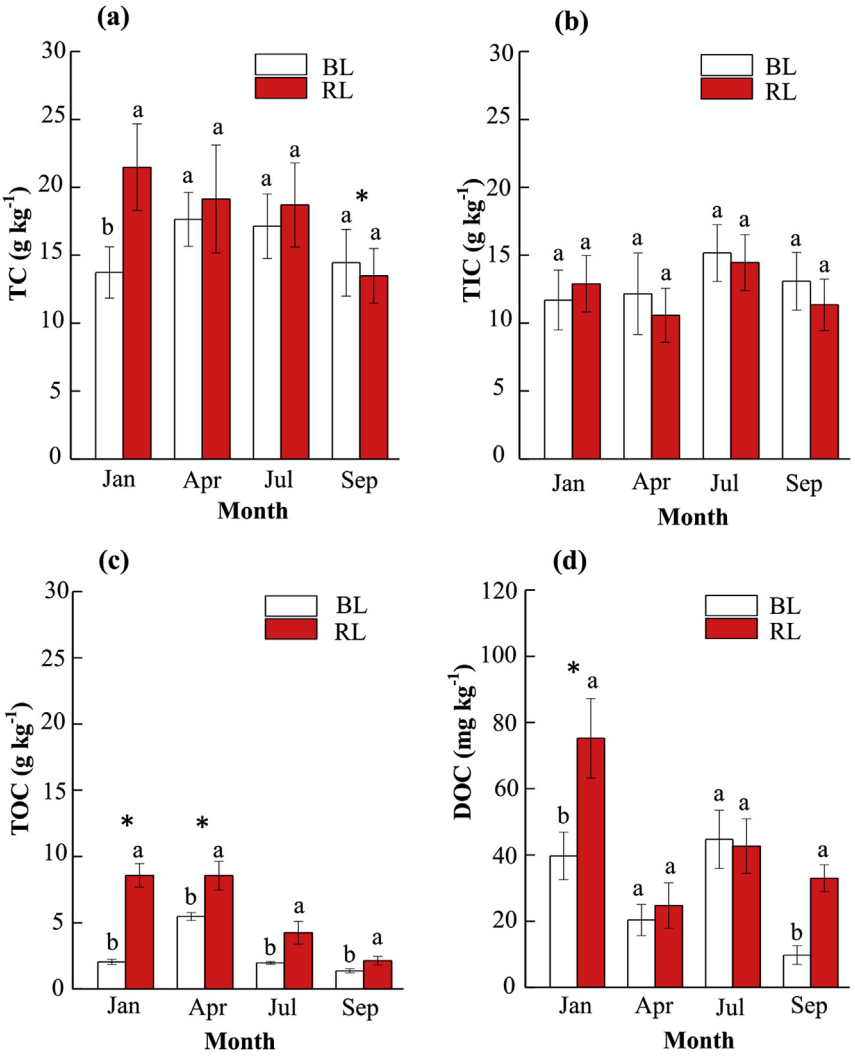

Fig. 1. The content of total C (TC) (**a**), total inorganic C (TIC) (**b**), total organic C (TOC) (**c**) and dissolved organic C (DOC) (**d**) in bare land (BL) and reed land (RL), respectively. Different small letters indicate significant difference between the BL and RL, which were analyzed by LSD test ($P < 0.05$) using SPSS 20.0, and asterisks indicate significant difference among the different seasons (i.e., January, April, July and September) using Duncan's multiple range test ($P = 0.05$) by means of SPSS 20.0.

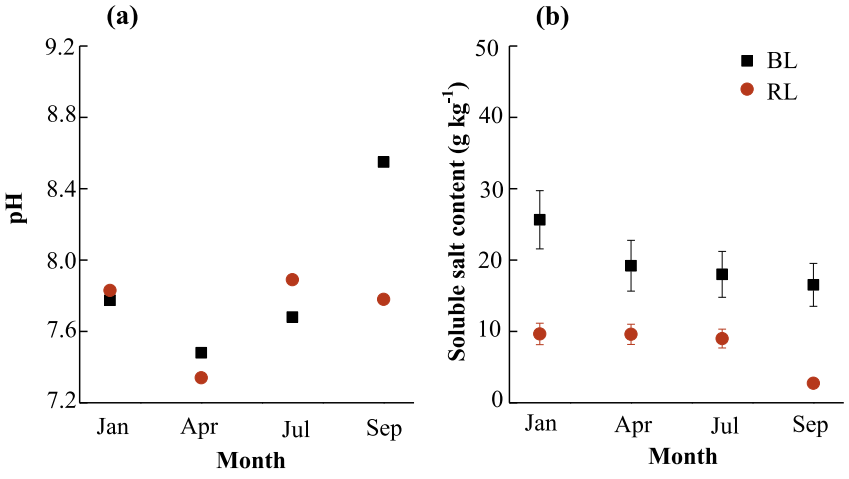

Fig. 2. The pH (**a**) and soluble salt content (**b**) of soils in the bare land (BL) and reed land (RL) in four different months (i.e., January, April, July and September).

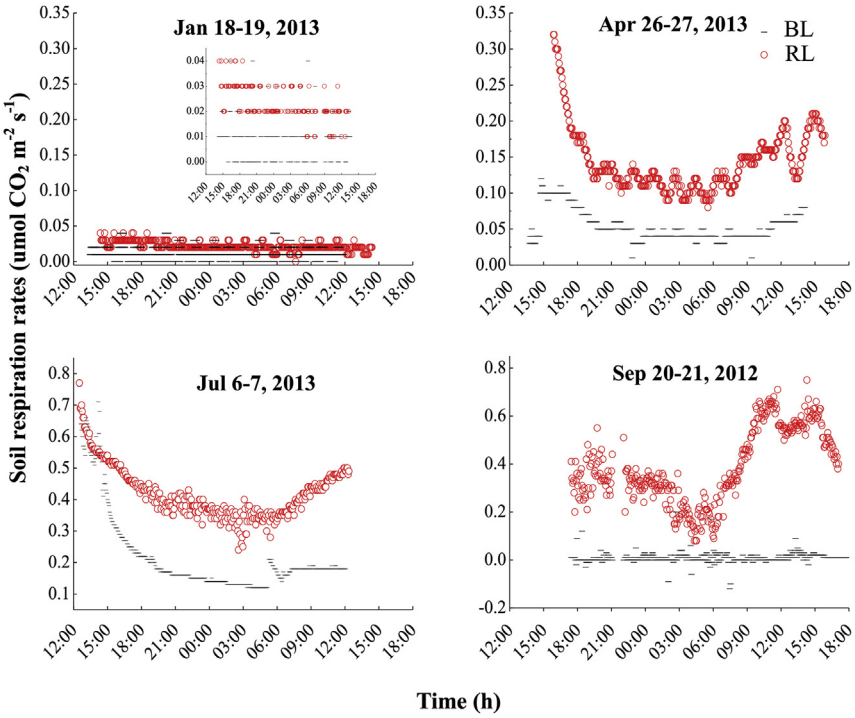

Fig. 3. The diurnal and seasonal variation of soil respiration in bare land (BL) and reed land (RL).

mean diurnal soil respiration rate (i.e., 0.22 μmol m^{-2} s^{-1}) in January. The diurnal variation of soil respiration rate in the BL was 0–0.04, 0.01–0.12, 0.12–0.76, and 0.12–0.20 μmol m^{-2} s^{-1} in January, April, July, and September, respectively. There was no significant difference between the diurnal soil respiration rate in January and September ($P > 0.05$), while significant differences were found in diurnal soil respiration rate among other three month (i.e., September, April, and July) ($P < 0.05$) (Fig. 3b–d). The seasonal variation of diurnal soil respiration rate (Fig. 1b–d) was in line with the results reported by Luo and Xing (2010) who suggested that soil temperature primarily influenced the soil respiration rate in Yellow River Delta.

3.3. Effect of soil surface temperature on soil respiration

The diurnal variation of soil surface temperature showed a similar trend to that of diurnal soil respiration rate (Fig. 4). Both of their maximum values were consistently found in July, and the minimum values appeared in January. The values of diurnal soil surface temperature reached up to the maximum at 12:00 a.m. in January and April, respectively, while the maximum value of soil temperature in other months (i.e., July and September) were observed at 14:30 p.m. All the minimum values of diurnal soil temperature in each month were found at the same time (around 6:00 a.m.). Significant differences in diurnal soil surface temperature were found among the different survey regions ($P < 0.05$). In April, July, and September, the soil surface temperatures in BL were significantly higher than those in RL ($P < 0.05$), in which the soil surface temperatures showed opposite results. The top soil surface temperatures were 39.7 °C and 27.0 °C in BL and RL, respectively, and the lowest temperatures was observed in 6:00–7:00 a.m., with the values of - 4.26 °C and −1.83 °C, respectively.

The regression analysis between soil respiration rate and soil surface temperature was based on Van't Hoff model (Fig. 5). The soil respiration rate was significantly exponential positive correlated with the soil surface temperature in both BL and RL ($P < 0.01$), except for September in BL (Fig. 5a and b), indicated that soil temperature could be the main factor to limit soil respiration (Schütt et al., 2014). In fact, soil respiration is an enzyme catalyzed biochemical process and the activity of enzyme is mainly mediated by temperature (Baldrian et al., 2013). The values of soil temperature sensitivity index (Q_{10}) for the RL and BL were 2.34 and 3.09, respectively (Fig. 5), suggesting that the soils in the BL were more sensitively affected by soil temperature compared to the soils in RL. In addition, there was a good correlation between the soil surface temperature and soil respiration rate observed in BL and RL when the soil surface temperature is below 5 °C (Fig. 5). However, the values of soil respiration rate showed deviations to the with a certain extent when the soil surface temperature was above 10 °C. The results suggested that the soil surface temperature is a primary factor limiting soil respiration, especially at low temperature range, while soil respiration could be more affected by other environmental factors when the temperature is suitable for soil respiration (Schütt et al., 2014).

3.4. Effect of soil physico-chemical properties on soil respiration

The soil physico-chemical properties (e.g., soil moisture, salinity, SOC, and pH) play crucial roles in mediating soil respiration (Schütt et al., 2014; Setia et al., 2011; Zhang et al., 2016), and most variations of soil respiration could be explained by their combined effect (Liu et al., 2016a,b; Mielnick and Dugas, 2000). The great effect of soil surface temperature on soil respiration could overshadow the effect of soil physico-chemical properties on soil respiration (Zhang et al., 2016), thus the diurnal soil respiration rate in January, in which the soil respiration was severely affected by low soil surface temperature, could not be taken into consideration in analyzing the effect of soil physico-chemical properties on soil respiration. Salt accumulation in soils has a pronounced negative effect on soil organic matter decomposition by suppressing the efficiency of

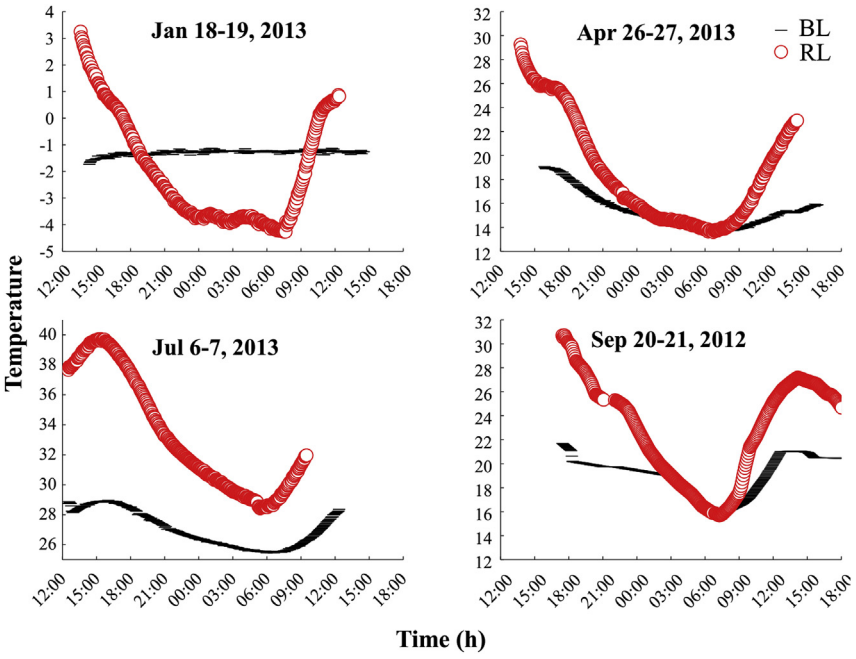

Fig. 4. The diurnal and seasonal variation of soil surface temperature in bare land (BL) and reed land (RL).

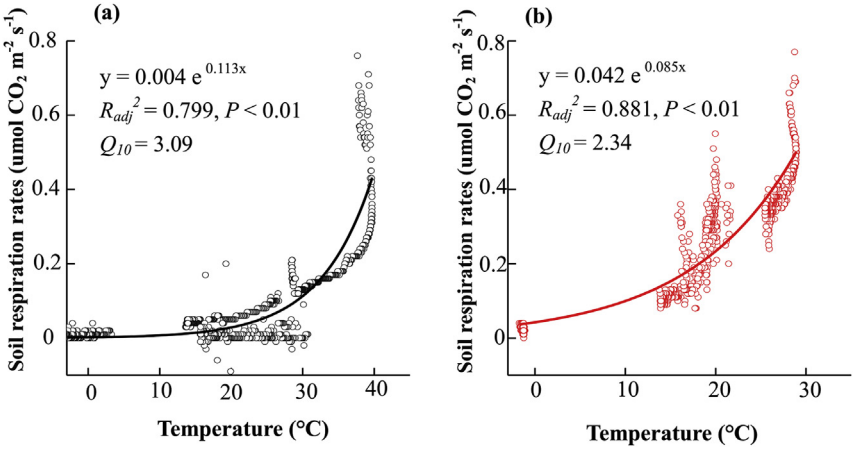

Fig. 5. Correlation between soil respiration rates and soil surface temperature in BL (**a**) and RL (**b**). Black lines are the exponential fit. Q_{10} represents the temperature sensitivity of soil respiration.

microbial C utilization. Thus, the high salinity of soils in this study could be one of the primary reasons for limiting soil respiration (Al-Busaidi et al., 2014; Mavi et al., 2012), which was confirmed by the significant negative correlation between soil respiration rate and the content of soluble salt (S) ($P < 0.01$, $r = 0.745$) or electrical conductivity (EC) ($P < 0.05$, $r = -0.738$) (Table 1). The low osmotic potential in salt-affected soils could cause microbial cells losing water, inhibiting microbial C mineralization (Setia et al., 2011). In contrast, Wong et al. (2009) reported that the increased ionic strength in soil solution could lead a more release of SOC from soil aggregates, providing an accurate simulation of CO_2 emissions. The inconsistent results could be ascribed to differences of soil texture (Chowdhury et al., 2011; Mavi et al., 2012), which the sandy soil with lower SOC and water content could have a greater sensitivity of respiration to salinity compared to the finer-textured soils. DOC in soils is the labile and easily-decomposed soil C stocks, contributing to stimulating soil microbial metabolism and transformation of soil organic and inorganic matter (Straathof et al., 2014), thereby the RL with greater soil respiration rate could attributed to the higher content of DOC (Fig. 1). The suggestion was supported by a significantly positive correlation between soil respiration rate and DOC ($P < 0.05$, $r = 0.508$). Meanwhile, the salts accumulation in soils may have adverse effect on SOC accumulation, and the increased ionic strength in soil solution could lead a loss of SOC from soil C pool (Wong et al., 2009), which could also account for the higher SOC content in RL relative to BL.

4. Conclusions

Regardless of the seasonal differences in soil respiration rate, the diurnal soil respiration rate in RL was significantly greater than that in the BL in the same season (e.g., April, July, and September), indicating that it should be cautious to elevate SOC pool in the degraded coastal wetland through restoring vegetation (increased plant biomass input). The dynamic variation of diurnal soil respiration rate in RL and BL consistently presented a “U” curve pattern

Table 1
Correlation analysis between soil respiration and soil physico-chemical properties.

	Soil respiration	DOC	DIC	TC	TOC	TIC	S	pH	EC	TN
DOC	0.508									
DIC	0.383	0.896*								
TC	−0.011	0.705	0.897*							
TOC	0.142	0.264	0.544	0.764*						
TIC	0.204	0.504	0.320	0.115	−0.553					
S	−0.745*	−0.003	0.032	0.228	−0.088	0.431				
pH	−0.146	−0.533	−0.605	−0.598	−0.730*	0.353	0.105			
EC	−0.738*	−0.234	−0.288	−0.135	−0.382	0.414	0.933**	0.314		
TN	0.790*	0.765*	0.731*	0.447	0.025	0.538	−0.350	−0.081	−0.510	
TP	−0.749*	0.013	0.080	0.297	−0.031	0.432	0.993*	0.125	0.897*	−0.300

The data in the table indicate the r values given by the Pearson's correlation analysis using SPSS 20.0. * indicate significant difference correlation at $P < 0.05$, and ** indicate significant difference correlation at $P < 0.01$.

in April, July, and September. Among the different seasons, the mean diurnal soil respiration rate in both BL and RL presented significant differences, with an order of July ≈ September > April > January. The varied soil respiration rate at different time in one day or different seasons were mainly attributed to the differences in soil surface temperature. Furthermore, our results confirmed that soil surface temperature was the main influencing factor controlling soil respiration at a low temperature range (< 5 °C). In addition, soil physico-chemical properties including salinity, OC content, and pH could also play crucial roles in mediating soil respiration.

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References

Al-Busaidi, K.T., Buerkert, A., Joergensen, R.G., 2014. Carbon and nitrogen mineralization at different salinity levels in Omani low organic matter soils. J. Arid. Environ. 100, 106–110.
Bai, J.H., Zhao, Q.Q., Lu, Q.Q., Wang, J.J., Reddy, K.R., 2015. Effects of freshwater input on trace element pollution in salt marsh soils of a typical coastal estuary, China. J. Hydrol. 520, 186–192.
Baldrian, P., Šnajdr, J., Merhautová, V., Dobiášová, P., Cajthaml, T., Valášková, V., 2013. Responses of the extracellular enzyme activities in hardwood forest to soil temperature and seasonality and the potential effects of climate change. Soil Biol. Biochem. 56, 60–68.
Chmura, G.L., Anisfeld, S.C., Cahoon, D.R., Lynch, J.C., 2003. Global carbon sequestration in tidal, saline wetland soils. Glob. Biogeochem. Cycles. 17 http://dx.doi.org/10.1029/2002GB001917.
Chowdhury, N., Marschner, P., Burns, R., 2011. Response of microbial activity and community structure to decreasing soil osmotic and matric potential. Plant Soil 344, 241–254.
Couto, T., Duarte, B., Caçador, I., Baeta, A., Marques, J.C., 2013. Salt marsh plants carbon storage in a temperate Atlantic estuary illustrated by a stable isotopic analysis based approach. Ecol. Indic. 32, 305–311.
Cui, B.S., Tang, N., Zhao, X.S., Bai, J.H., 2009. A management-oriented valuation method to determine ecological water requirement for wetlands in the Yellow River Delta of China. J. Nat. Conserv. 17, 129–141.
FAO, 2000. The State of World Fisheries and Aquaculture 2000. FAO, Rome, Italy.
Fennessy, M.S., 2014. Wetland ecosystems and global change. In: Fennessy, M.S. (Ed.), Global Environmental Change. Springer, Netherlands, pp. 255–261.
Gargouri, K., Rigane, H., Arous, I., Touil, F., 2013. Evolution of soil organic carbon in an olive orchard under arid climate. Sci. Hortic. 152, 102–108.
Han, G.X., Yu, J.B., Li, H.B., Yang, L.Q., Wang, G.M., Mao, P.L., Gao, Y.J., 2012. Winter soil respiration from different vegetation patches in the Yellow River Delta. China. Environ. Manage.50 39–49.
Han, G.X., Luo, Y.Q., Li, D.J., Xia, J.Y., Xing, Q.H., Yu, J.B., 2014. Ecosystem photosynthesis regulates soil respiration on a diurnal scale with a short-term time lag in a coastal wetland. Soil Biol. Biochem. 68, 85–94.
Howard, J., Hoyt, S., Isensee, K., Telszewski, M., Pidgeon, E., 2014. Coastal Blue Carbon: Methods for Assessing Carbon Stocks and Emissions Factors in Mangroves, Tidal Salt Marshes, and Seagrasses. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature, Arlington, Virginia.
IPCC, 2013. Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. IPCC, Switzerland.
Jansson, C., Wullschleger, S.D., Kalluri, U.C., Tuskan, G.A., 2010. Phytosequestration: carbon biosequestration by plants and the prospects of genetic engineering. BioScience 60, 685–696.
Jiang, D.J., Fu, X.F., Wang, K., 2013. Vegetation dynamics and their response to freshwater inflow and climate variables in the Yellow River Delta, China. Quatern. Int. 304, 75–84.
Kong, D., Miao, C.Y., Borthwick, A.G.L., Duan, Q.Y., Liu, H., Sun, Q.H., Ye, A.Z., Di, Z.H., Gong, W., 2015. Evolution of the Yellow River Delta and its relationship with runoff and sediment load from 1983 to 2011. Hydrol. Sci. J. 520, 157–167.
Liu, B.Q., Mou, C.C., Yan, G.Y., Xu, L.J., Jiang, S.L., Xing, Y.J., Han, S.J., Yu, J.H., Wang, Q.G., 2016a. Annual soil CO_2 efflux in a cold temperate forest in northeastern China: effects of winter snowpack and artificial nitrogen deposition. Sci. Rep. 6, 18957.
Liu, X.F., Zhang, W., Zhang, B., Yang, Q., Chang, J., Hou, K., 2016b. Diurnal variation in soil respiration under different land uses on Taihang Mountain, North China. Atmos. Environ. 125, 283–292.
Lu, Q.Q., Bai, J.H., Gao, Z.Q., Wang, J.J., Zhao, Q.Q., 2016. Effects of water level and salinity on total sulfur contents in salt marsh soils of the Yellow River Delta, China. Wetlands 36, 137–143.
Luo, X.X., Wang, L.Y., Liu, G.C., Wang, X., Wang, Z.Y., Zheng, H., 2016. Effects of biochar on carbon mineralization of coastal wetland soils in the Yellow River Delta, China. Ecol. Eng. 94, 329–336.
Luo, X.X., Xing, Z.Q., 2010. Comparative study on characteristics and influencing factors of soil respiration of reed wetlands in Yellow River Estuary and Liaohe River Estuary. Procedia Environ. Sci. 2, 888–895.
Mavi, M.S., Marschner, P., Chittleborough, D.J., Cox, J.W., Sanderman, J., 2012. Salinity and sodicity affect soil respiration and dissolved organic matter dynamics differentially in soils varying in texture. Soil Biol. Biochem. 45, 8–13.
Mcleod, E., Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Silliman, B.R., 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Front. Ecol. Environ. 9, 552–560.
Mielnick, P.C., Dugas, W.A., 2000. Soil CO2 flux in a tallgrass prairie. Soil Biol. Biochem. 32, 221–228.
Moriyama, A., Yonemura, S., Kawashima, S., Du, M., Tang, Y., 2013. Environmental indicators for estimating the potential soil respiration rate in alpine zone. Ecol. Indic. 32, 245–252.
Moyano, F.E., Manzoni, S., Chenu, C., 2013. Responses of soil heterotrophic respiration to moisture availability: an exploration of processes and models. Soil Biol. Biochem. 59, 72–85.
Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A., Sifleet, S., Craft, C., Fourqurean, J.W., Boone Kauffman, J., Marbà, N., Megonigal, P., Pidgeon, E., Herr, D., Gordon, D., Baldera, A., 2012. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PLoS One 7, e43542.
Schindlbacher, A., Wunderlich, S., Borken, W., Kitzler, B., Zechmeister-Boltenstern, S., Jandl, R., 2012. Soil respiration under climate change: prolonged summer drought offsets soil warming effects. Glob. Change Biol. 18, 2270–2279.
Schütt, M., Borken, W., Spott, O., Stange, C.F., Matzner, E., 2014. Temperature sensitivity of C and N mineralization in temperate forest soils at low temperatures. Soil Biol. Biochem. 69, 320–327.
Setia, R., Marschner, P., Baldock, J., Chittleborough, D., Smith, P., Smith, J., 2011. Salinity effects on carbon mineralization in soils of varying texture. Soil Biol. Biochem. 43, 1908–1916.
Spencer, T., Schuerch, M., Nicholls, R.J., Hinkel, J., Lincke, D., Vafeidis, A.T., Reef, R., McFadden, L., Brown, S., 2016. Global coastal wetland change under sea-level rise and related stresses: the DIVA Wetland Change Model. Glob. Planet. Change 139, 15–30.
Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., Singh, K., Wheeler, I., Abbott, L., Angers, D.A., Baldock, J., Bird, M., Brookes, P.C., Chenu, C., Jastrow, J.D., Lal, R., Lehmann, J., O'Donnell, A.G., Parton, W.J., Whitehead, D., Zimmermann, M.,

2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agric. Ecosyst. Environ. 164, 80–99.
Straathof, N.J., Gemoets, H.P., Wang, X., Schouten, J.C., Hessel, V., Noël, T., 2014. Rapid trifluoromethylation and perfluoroalkylation of five-membered heterocycles by photoredox catalysis in continuous flow. Chem. Sus. Chem. 7, 1612–1617.
Sul, W.J., Asuming-Brempong, S., Wang, Q., Tourlousse, D.M., Penton, C.R., Deng, Y., Rodrigues, J.L.M., Adiku, S.G.K., Jones, J.W., Zhou, J.Z., Cole, J.R., 2013. Tropical agricultural land management influences on soil microbial communities through its effect on soil organic carbon. Soil Biol. Biochem. 65, 33–38.
Sun, Q.H., Miao, C.Y., Duan, Q.Y., Kong, D.X., Ye, A.Z., Di, Z.H., Gong, W., 2014. Would the 'real' observed dataset stand up? A critical examination of eight observed gridded climate datasets for China. Environ. Res. Lett. 9, 015001. http://dx.doi.org/10.1088/1748-9326/9/1/015001.
Vaidyanathan, G., 2011. 'Blue Carbon' plan takes shape. Nature 112.
Wang, J.J., Bai, J.H., Zhao, Q.Q., Lu, Q.Q., Xia, Z.J., 2016. Five-year changes in soil organic carbon and total nitrogen in coastal wetlands affected by flow-sediment regulation in a Chinese delta. Sci. Rep. 6, 21137.
Wong, V.N., Dalal, R.C., Greene, R.S., 2009. Carbon dynamics of sodic and saline soils following gypsum and organic material additions: a laboratory incubation. Appl. Soil. Ecol. 41, 29–40.
Yan, M.F., Zhang, X., Zhou, G., Gong, J., You, X., 2011. Temporal and spatial variation in soil respiration of poplar plantations at different developmental stages in Xinjiang, China. J. Arid. Environ. 75, 51–57.
Yu, J., Wang, Y., Li, Y., Dong, H., Zhou, D., Han, G., Wu, H., Wang, G., Mao, P., Gao, Y., 2012. Soil organic carbon storage changes in coastal wetlands of the modern Yellow River Delta from 2000 to 2009. Biogeosciences 9, 2325–2331.
Zedler, J.B., Kercher, S., 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annu. Rev. Env. Resour. 30, 39–74.
Zhang, C.B., Wang, J., Liu, W.L., Zhu, S.X., Ge, H.L., Chang, S.X., Chang, J., Ge, Y., 2010. Effects of plant diversity on microbial biomass and community metabolic profiles in a full-scale constructed wetland. Ecol. Eng. 36, 62–68.
Zhang, Q., Meng, W.Q., Li, H.Y., 2016. Research of the Diurnal Soil Respiration Dynamic in Two Typical Vegetation Communities in Tianjin Estuarine Wetland. IOP Conference Series: Earth and Environmental Science, vol. 41. IOP Publishing, p. 012016. http://dx.doi.org/10.1088/1755-1315/41/1/012016.
Zhao, Q.Q., Bai, J.H., Liu, Q., Lu, Q.Q., Gao, Z.Q., Wang, J.J., 2016. Spatial and seasonal variations of soil carbon and nitrogen content and stock in a tidal salt marsh with *Tamarix chinensis*, China. Wetlands 36, 145–152.
Zhou, Z.Y., Zhang, Z.Q., Zha, T.G., Luo, Z.K., Zheng, J.M., Sun, O.J., 2013. Predicting soil respiration using carbon stock in roots, litter and soil organic matter in forests of Loess Plateau in China. Soil Biol. Biochem. 57, 135–143.